SCIENCE

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MSS. intended for publication and books, etc., intended for review should be sent to Professor J. McKeen Cattell, Garrison-on-Hudson, N. Y.

THE AERIAL TRANSMISSION PROBLEMS[1]

THE title of my address suggests that I propose to discuss the problems connected with wireless telegraphy and telephony. It should be observed, however, that ordinary telegraphy and telephony and electrical transmission of large amounts of power is aerial transmission and faces some of the problems which confront us to-day in wireless transmission. But, of course, the problems of aerial transmission in their relation to wireless telegraphy and telephony present their most interesting aspect and I shall, therefore, devote most of my time this evening to this particular aspect, of the problem of aerial transmission.

Permit me now to differentiate, briefly, wireless transmission from ordinary electrical transmission.

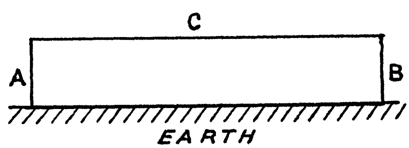

FIG. 1.

Fig. 1 represents the simplest form of ordinary electrical transmission. A wire, *ACB*, is connected to the earth at each end. A generator station at *A* sends electrical energy to receiving apparatus stationed at *B*. The motion of electricity started at *A* is transmitted along the wire *C* to the station *B* and then is completed through the conducting ground between *B* and *A*.

[1] An address delivered before the National Academy of Science, at its meeting in New York, November 15, 1915.

Fig. 2 represents the simplest form of wireless transmission. An electrical gen-

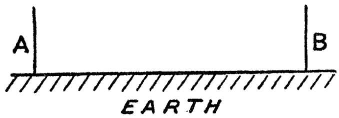

Fig. 2.

erator at *A* sends through a vertical wire electrical energy to a vertical wire at station *B*. There is motion of electricity between *A* and *B*, but only through the earth. The second case is similar to the first except that in the second case there is no wire *C*, connecting station *A* to station *B*; hence, on account of the absence of the connecting wire *C*, we call the second method of transmission a "wireless" method. This second method is particularly important when it is impossible to employ a connecting wire between the two stations, as, for instance, between two ships at sea, or between a ship and the shore.

This more or less insignificant difference in the structures, by means of which we transmit, necessitates, however, the employment of almost radically different electrical actions in order to transmit energy from *A* to *B*. Whereas in the first case we can transmit from *A* to *B* any reasonable amount of energy by a constant or a slowly varying motion of electricity, we have to adopt in the second case a very rapidly oscil-

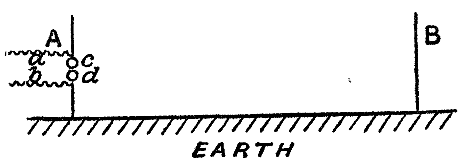

Fig. 3.

lating motion of electricity. The simplest and historically the oldest method of producing a rapidly oscillating motion of electricity was obtained as follows: The vertical wire at the transmitting station *A*, called the antenna, has an air gap *cd* and the two parts of the antenna, the upper part which is insulated, and the lower part which is connected to the earth, are connected by means of wires *a* and *b* to a very high electrical tension such as is employed in our automobiles for ignition or in the production of X-rays by means of the X-ray tubes and the induction coil. This high electrical tension forces one kind of electricity into the upper part of the antenna and the opposite kind into the lower part of the antenna which is connected to the earth. The two parts of the antenna form the two conducting coatings of a Leyden jar; the surrounding atmosphere, of which the air gap *cd* is a part, separates the two coatings. When the electrical tension is very high it breaks through the air space *cd*, that is, a spark jumps between the two metal balls *cd* and forms there a conducting path, that is an easy path for the motion of the electricities which are separated, one crowded into the upper part of the antenna, and the other into the lower part and the earth. These two separated electricities which attract each other will rush toward each other as soon as the passage through the air gap *cd* has been established, and they will move as fast as the laws of motion of electricities command them to do. Now these laws demand that this motion be an oscillatory one. This oscillatory motion of electricity during a discharge of a Leyden jar was discovered by our great Joseph Henry in 1840 when he was professor of physics at Princeton College, and the laws of motion were first formulated in 1855 by the famous William Thomson, who died a few years ago as Lord Kelvin. The oscillatory motion of electricity and the laws governing it can be best illustrated by the following simple mechanical analogy. A stiff steel tongue *ab* which is fastened at its lower end *a* to a table is displaced by the tension of a string *d* from

its position of equilibrium. Increase the tension until the string *d* breaks when the displaced steel tongue is released; it will then return to its normal position after per-

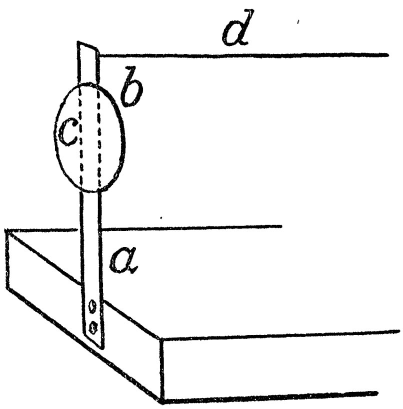

FIG. 4.

forming a few oscillatory movements. The analogy between the motion of the steel tongue and the motion of electricity referred to above is quite complete and to make it even more complete I attach a cardboard disc *C* which by transferring a considerable part of the motion of the tongue to the surrounding air will accelerate the dying out of the oscillatory motion of the tongue by the transference of the energy of the vibrating cardboard to the surrounding air. Here is a tuning fork which I pluck with my fingers instead of employing the tension of the string, or which is still better, I give it a gentle impulse with a soft hammer. After each impulse the fork oscillates, imparting some of its motion to the surrounding air, and the vibratory motion of the air propagated in all directions impinges upon your auditory organs and thereby produces in your consciousness the sensation of sound. In the same manner the vibratory motion of electricity in the antenna is communicated to the electricity near the surface of the earth, causing it to move in the same vibratory fashion; these vibrations spread out in all directions and travel along the surface with the velocity of light, that is, about 180,000 miles a second. This propagation along the surface of the earth of the oscillatory motion of electricity is called electrical wave motion, just as the propagation of the vibratory motion of the tuning fork through the air is called wave motion. Just as the sound waves produced by the vibration of the tuning fork or by my vocal cords spread out in every direction, getting feebler as they progress further and further, but producing a sensation of sound in every healthy ear which they find anywhere, so the propagation of the vibratory motion of electricity along the surface of the earth spreads out in every direction, getting feebler as it advances further from the sending antenna, but producing a definite effect in every upright wire like *B* in Fig. 3, which effect can be detected very clearly by a suitable electrical instrument connected with the wire *B*. This, briefly stated, is wireless transmission of electrical signals.

We often hear that wireless transmission is only a practical application of electrical waves discovered by a German, the late Professor Hertz; that it is an art which formed its first roots in German soil, whereas in reality it is a particular case of the oscillatory motion of electricity discovered by Joseph Henry and the laws of which were formulated by Kelvin. It is true that Hertz employed these oscillations more skilfully than anybody else ever did prior to his time, and thereby succeeded improving experimentally the complete validity of the physical foundation of the great electromagnetic theory which was conceived and formulated by Clerk Maxwell, the great Scotch physicist. It is also true that Guglielmo Marconi in 1895, when a mere youth of twenty-one, fascinated by the beauty of the Hertzian experiments, was busy with Hertzian electrical oscillators

when he suddenly discovered that an oscillator connected to the earth, as described in Fig. 3, was much more efficient than any other form of oscillator in propagating an oscillatory motion of electricity from any given point of the earth to any other point. That discovery gave birth to wireless telegraphy. But, nevertheless, this discovery could have been made prior to the time of Hertz by any one who understood the work of Henry and of Kelvin and interested himself in the study of electrical oscillators of various types. I think that Marconi discovered wireless telegraphy; he did not invent it. The inventing period in this new art started after the discovery was made and when various problems connected with the development of this new art presented themselves.

The earliest attempts to advance the new art were in the direction of increasing the distance which could be bridged over by this new method of electrical transmission. As early as 1902 Marconi attempted the bold experiment of sending wireless signals across the Atlantic. These attempts resulted at first in an enormous increase in the height of the antennæ and the power of the generators which create the electrical oscillations at the sending station. The wireless structures employed as sending antennæ were anything but wireless, and the generating stations which fed them were veritable thunder and lightning factories. The roar of the thundering sparks transmitting signals between England and Newfoundland would terrify the whole neighborhood of the transmitting station, and yet at the receiving station there would be only very faint clicks in a very sensitive telephone held over the anxious ear of a skilled operator. Physicists with artistic temperament, that is, with a sense of right proportions, always felt that these thunder and lightning factories had no place in wireless transmission. Three years ago I suggested that if a little more science were put into the General Electric Company we would soon have a noiseless generator which would replace those thundering spark-gaps. Well, the General Electric Company has put a little more science into Schenectady and we have today a generator which can supply any reasonable amount of electrical power in the form of electrical oscillations of very high frequency, say, twenty thousand to two hundred thousand vibrations per second, and it supplies it smoothly and silently. The horrible racket of thunder and lightning has disappeared for good from the wireless transmitting stations.

In the meantime another great and wonderful advance has reached the wireless transmitting station. This advance is so far reaching in its purely scientific aspect that I feel constrained to devote to it a few brief moments. Consider a generator of electrical oscillations sending out from a wireless station at A (Fig. 5) a continuous train of electrical waves ab of high frequency or pitch, say fifty thousand periods per second. A person with a telephone receiver at the receiving station B would hear nothing, because the pitch of the re-

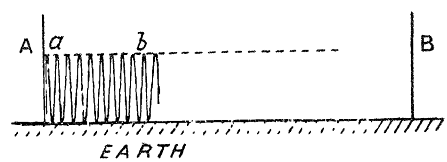

FIG. 5.

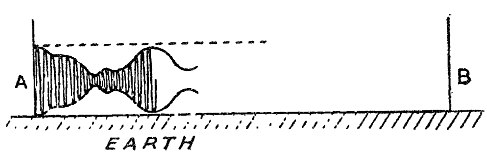

FIG. 6.

ceived waves is too high. Suppose now that by some means the generator is made to vary the amplitude of the outgoing

waves as indicated by the thick wavy curve in Fig. 6, and suppose that these variations follow the law of variation of sound waves in articulate speech, then the man holding a telephone to his ear at the receiving station *B*, equipped with a suitable apparatus, will hear articulate speech. This idea is not new; I disclosed it in 1902 to Professor Henry Perkins, of Trinity College, Hartford, and I consider the idea as obvious. But what I do not consider as obvious is the manner in which a huge generator of electrical power can be made to vary the power which it delivers in that most complicated way which we human beings practise when we vibrate our vocal cords in order to produce articulate speech. When the Western Electric Company and the American Telephone and Telegraph Company transmitted articulate speech between Arlington and Honolulu they actually controlled by the human voice the operation of a huge electrical generator generating many horse power, and it is plain that the same method can be easily extended so as to control any amount of power by the human voice. It is, indeed, a great achievement. It may be claimed that the achievement is nothing startlingly new, for do we not know that with a tiny spark we may start a huge explosion and do we not see every day that the chauffeur by minute twists of his hand or foot can regulate the power of the gas engine in our automobiles? Yes, I admit that there is a resemblance, but the resemblance is a very coarse one. When you find a chauffeur who can regulate the movement of his car in such a way that it will vibrate in accordance with the vibrations of articulate speech, then that chauffeur will have accomplished the same thing which the operator at the Arlington Station did when by the controlling action of his voice he made his huge generator speak the words which were heard at Honolulu, five thousand miles away. And yet the achievement is perhaps not quite as new as it might appear. When a Paderewsky with Beethoven's Sonata in his head makes Beethoven's ideas control the strenuous movements of his body which agitate the strings of the piano, then I see something which the operator at Arlington might have been unconsciously copying. I throw this out as a suggestion to the biologists, the physiologists, and the neurologists, who are not always aware of what is going on in other departments of physical science, just as we physicists are often totally ignorant of the great researches in biology, physiology and neurology.

Let us now turn our attention to the electrical waves which carried that articulate message from Arlington to Honolulu and examine their condition when they arrived at Honolulu. These waves were so feeble that no electrical instrument ever invented by man could, unaided, ever detect their presence. This brings me to a point which I discussed before this academy just four years ago. I told you then that I had discovered an electrical machine which stimulated by a feeble electrical wave of high frequency would reproduce that wave magnified to any extent. I believe that in that discussion was the first mention of the electrical "amplifiers" which play a most important part to-day in wireless transmission. It is far from me to claim the whole credit for the work which has been done in this direction; on the contrary, most of the credit for developing the idea of electrical amplifiers of to-day and of giving them a thoroughly fool-proof form belongs to the research laboratory of the General Electric Company and of the American Telephone and Telegraph Company, and I cheerfully congratulate them upon the wonderful achievement.

Now what is an amplifier of these high frequency electrical waves? Broadly speak-

ing, it is a local source of electrical energy which stimulated by an electrical wave no matter how feeble will give a perfect reproduction of that wave magnified to any extent that may be desirable. When the electrical wave conveying speech from Arlington to Honolulu arrived at Honolulu it was perfectly exhausted and so feeble that its action could not produce any perceptible direct effect upon any instrument ever constructed by man. The electrical amplifier, that is, the local electrical generator, then threw in its wonderful work. Stimulated by the feeble wave it reproduced it in a tremendously magnified form without in any way modifying its character. The man at Honolulu, with the aid of the local amplifier, not only heard the voice of Arlington, five thousand miles away, but by the characteristics of the articulation he recognized the speaker: so perfect was the reproduction by the amplifier! In fact, we may say that the electrical amplifier at Honolulu stimulated by the waves coming from Arlington created over again at Honolulu the articulate speech uttered at Arlington. Permit me now to offer a suggestion which has occurred to me often, and which, I think, may be of some interest to the biologist and the neurologist. We all know that the eye, the ear, and other organs which are the instruments of our perceptions are extremely sensitive. For instance, the amount of energy conveyed to the eye by light, which is just visible, is almost incredibly small. The question arises now, does that energy produce in us directly the sensation of light or does it serve as a stimulus, only, for a local source of energy, the sensatory organs, which amplify it and reproduce it somewhat in the manner as the electrical amplifier reproduces, on a very much magnified scale, the faint traces of a wireless wave? The structure of the nervous system seems to support this bit of speculation and I trust that you will not be too severe with me for indulging in it.

From this very rough sketch which I have just drawn for you describing the present state of wireless transmission it appears that there are at present no obstacles in the way of extending the distance of wireless communication to any point on the earth. And yet there are, and they are of the most formidable character. These obstacles are due to the interference produced by electrical waves which are passing through the terrestrial atmosphere continuously. One may say that electrical waves are just as numerous in the atmosphere as water waves are on the surface of the sea. They are of the same general character and probably due to the same causes as the electrical waves which interfere with our telephone and telegraph lines and with power transmission wires during a thunderstorm. They are, in fact, the electrical tremors of minute thunderstorms or of powerful but very distant thunderstorms. We were not aware of their presence until we attempted to magnify the minute electrical wave coming from a very distant signalling station. An engineer of the American Telephone and Telegraph Company who was on the Pacific Coast and watched for the famous telephone message from Arlington reports that at times it was drowned completely in a roar of musketry. This roar was due to the action of the electrical waves produced by the incessant electrical discharges in the atmosphere. The wireless telegraph engineer calls these discharges the "static" and he hates them, because they interfere with his business, but the physicist and particularly the meteorologist will hail their appearance with delight, because they offer him a new and most unexpected aid for the study of the activities in the terrestrial atmosphere.

All attempts up to the present time which

the so-called "practical" wireless engineer has made in the direction of overcoming the interference of the "static" consisted in increasing continually the power applied at the signalling station so as to make the signals at their arrival at the receiving station stronger than the signals made there by the static. These attempts failed, as they should. The static is an act of God and his acts can not be neutralized by brute force. The machinery of nature will not interfere with the machinery constructed by man if man puts a sufficient amount of intelligence into his machine. In other words, the practise of the wireless art needs more pure science before it can expect to overcome the very serious interferences due to the action of the static. Ordinary electrical tuning will not do, because every system which is highly selective through ordinary tuning is also highly sonorous. Every tap of the static will cause it to vibrate and it will vibrate in the same way as when it is under the action of the signalling waves. We must look for some other form of electrical selectivity, and this is the last point which I wish to bring before you now, but only very briefly.

The eye sees a very narrow strip of wave frequencies which are sent from a radiating body; the ear hears a very narrow strip of wave frequencies which vibrating bodies can send out. Physiological optics and physiological acoustics deal with these remarkable facts. Now the reason why the eye is blind and the ear is deaf to an enormous range of frequencies is certainly not due to anything like ordinary selectivity produced by tuning. The selectivity must be due to something else. Physicists see resonance and tuning wherever they find selectivity, but it is high time to formulate broader views.

Fifteen years ago I published several investigations which deal with electrical motion in sectional wave conductors. One of these resulted in the now well-known loaded telephone line. I regret that the technical importance of this invention, by attracting too much attention, has overshadowed completely the full meaning of the general mathematical theory which underlies it. This theory says that sectional wave conductors can be made which will absorb almost completely all waves above or below a certain small range of frequencies, and the selectivity thus obtained has nothing to do with ordinary electrical tuning. In other words, the selectivity of the eye and of the ear can be imitated by coarse structures like sectional wave conductors. Electrical pulses produced by the static are for the most part very short and their action is equivalent to the action of highly damped electrical oscillations of very high pitch. This action can be entirely absorbed so that no part of it reaches the receiving apparatus of a wireless receiving station if between the antenna and the receiving apparatus a sectional wave conductor is employed which will not transmit electrical waves of a frequency higher than a given range of frequencies. The station becomes then an ear which is quite sensitive for frequencies which are in the vicinity of the signalling frequency, but which is stone deaf to frequencies which are considerably beyond this range as most static disturbances are. Similarly, a sectional wave conductor can be constructed which is quite responsive to frequencies in the vicinity of the signalling frequency, but absorbs almost completely everything below this range. My theoretical and experimental investigations encourage me in the belief that a perfect barrier has been found against disturbances due to the so-called static, and that the distances of uninterrupted wireless telegraphy and telephony will be very greatly increased.

M. I. Pupin